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SOME GEOLOGICAL EVIDENCE

REGARDING THE

AGE OF THE EARTH

BY

J. G. GOODCHILD,
H.M. Geological Survey, F.G.S., F.Z.S., M.B.O.U.

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PROCEEDINGS

OF THE

ROYAL PHYSICAL SOCIETY.

SESSION CXXVI.

Wednesday, 18th November 1896.—Professor J. STRUTHERS, M.D., LL.D., President, in the Chair.

Mr J. G. GOODCHILD, H.M. Geological Survey, F.G.S., F.Z.S., M.B.O.U., retiring Vice-President, delivered the following opening address, entitled "Some Geological Evidence regarding the Age of the Earth":—

(Published 13th April 1897.)

Introduction.—Geologists from time to time have attempted many estimates regarding the Age of the Earth, and especially that portion of the Earth's history represented by the interval between to-day and the period when the oldest strata containing fossils were laid down. All who have made the attempt have realised that it is impossible, with our present knowledge, to state the antiquity of the rocks in question in terms of centuries, thousands of years, or even in millions. All we can feel sure of is that the records of the rocks fully justify us in claiming for the earth an antiquity so vast as to be far beyond the power of the human intellect to grasp. When a geologist wishes to form even some faint conception of what this antiquity implies, he turns to astronomy, and, after having formed in his mind some conception of what is meant by astronomical distance, he is able, in some measure, to transfer his conception of those vast intervals of space to

213324

the conception of the equally vast intervals of time with which it is his own special province to deal.[1]

"Vague, indefinite, but unquestionably vast beyond conception," is a phrase that must recur to the minds of most geologists when referring to the subject of Geological Time. Yet, indefinite though it must long remain, it seems to me that almost every attempt that has been made at reasoning out an answer to the question, "What is meant by Geological Time?" has contributed something that has helped to make our ideas upon the subject more and more definite. Speculation is not without its uses in science; and even when it may be based more or less upon error, the correction of that error may at least help to guide others into the track which, sooner or later, will lead them up to the truth.

In dealing with this subject of the Age of the Earth, the fundamental idea which a geologist steadily keeps in mind is that all the changes, physical and biological, which the records of the rocks inform us have taken place upon the Earth in the Past, can only be understood and properly interpreted by reference to changes of the same nature which are known to be in progress during the Present. This, of course, does not imply absolute uniformitarianism (as this is commonly understood), but it allows for catastrophism in certain exceptional cases, along with normal uniformity of action in the rest. The geologist obtains abundant confirmation of the justice of this view in the fact that, throughout the whole series of rocks, and even throughout those strata which are older than the most ancient yet known to contain records of life, the manifestations of Nature's forces show no sign of any action different, in either degree or kind, from those which are known to be at work at the present day. Rain fell in those early days much as it falls now. Wind blew then with apparently no greater force than it does to-day. The tides and currents of those early periods appear to have obeyed exactly the same laws that they do now, and in no

[1] The astronomical models in the Museum of Practical Geology, and the more extended set placed in the Gallery of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art, were set out with the express object here referred to.

case do they show any sign of having acted with greater energy than they do at the present day. In short, even as far back as the commencement of the Cambrian Period, the two great geological factors, solar energy and gravitation, appear to have operated then very much as they do now. To a geologist this merely indicates that the close of what has been termed the Astronomical History of the Earth terminated many millions of years prior to the Cambrian Period, and that the Earth must have been in a condition suitable for life through a long period of the time when the Archæan rocks were in process of formation.

Turning to the records supplied by fossils, we find that the life-conditions during Lower Cambrian times were in no respect yet discovered different from what such conditions are to-day. Organisms then, as now, changed under the influence of varying environment and other biological factors at, apparently, at least as slow a rate as now. Hence biologists concur with geologists in claiming, as requisite for the development of the existing forms of life, an interval of time fully as vast as that required to account for the physical changes which are known to have taken place upon the earth.

It is true that some there were, and perhaps there may be some still, who, taking note of these facts relating to the Earth's history, declared that they could perceive no vestige of a beginning, and no prospect of an end. It was only natural that a reaction should set in against views so directly opposed to all that we know through the researches of the astronomer. Mathematicians and physicists of eminence took up the question, and discussed it from their own standpoints, basing their conclusions upon what, at the time, appeared to be well-established facts. The conclusions referred to were by no means identical with those to which geologists had been led. Lord Kelvin, for example, boldly stated his opinion that all geological history showing continuity of life must be limited within some such period as 100,000,000 of years; and Professor Tait was disposed to allow even very much less than that. Lord Kelvin has lately considerably modified the view here referred to,[1] but

[1] "Nature," vol. li., 1895, p. 257.

even yet geologists in general do not feel satisfied with the concession.

It certainly requires that a geologist should feel that he can place considerable reliance upon the value of his own set of facts and inferences before he can venture to call in question the validity of the conclusions arrived at by men of undoubted eminence in their own subjects, such as Lord Kelvin and Professor Tait are. Nevertheless, geologists still shake their heads, and repeat with approval Professor Huxley's well-known saying that "Mathematics may be compared to a mill of exquisite workmanship, which grinds you stuff of any degree of fineness; but, nevertheless, what you get out depends upon what you put in; and as the finest mill in the world will not extract wheat-flour from peascods, so pages of formulæ will not get a definite result out of loose data." In the following pages I shall confine my attention to the purely geological side of the question, leaving the physicists to take up the discussion and deal with it in the light of new facts and views. The results at which they will eventually arrive will not, I feel confident, prove so discordant with geological evidence as those to which reference has just been made.

I propose in the following pages to pass in review certain changes which are known to have taken place in the past, beginning with the latest periods and working backward. I shall therefore commence with the Glacial Period.

Time required for the Physical Changes that have taken place during the Tertiary Period.—One of the best regions in the British Islands for the study of the changes which have taken place since the commencement of the Tertiary Period is to be found in the Inner Hebrides. It is true that, in regard to the sequence of glacial events, these islands do not afford us evidence quite as satisfactory as do other regions to the east. This, I think, is probably owing to the fact that the influence of the complex conditions known as the "Gulf Stream" (whether in the bodily transfer of warm water, or in the northward transfer of aqueous vapour, which, by its condensation into rain, warms the air—matters not in the present connection), was maintained close to the edge of the present 100-fathom line west of Europe all through the

Glacial Period. Consequently, from the West of Ireland to the Lofoten Isles, or farther north still, the evidence of glaciation is mainly confined to the low ground. Be that as it may, there must have been an excessively heavy rainfall there, if there was not much snow; and although the low ground, in, for example, Loch Coruisk in Skye, underwent considerable erosion through the action of simple glaciers of large size, the high ground there, as in the Lofoten Islands, was probably never overridden by an ice-sheet for any lengthy period, if it was so overridden at all. I only refer to the matter here in order that some reference may be made to the time which has probably elapsed since the Climax of the Glacial Period. Taking into account the small extent of the physical changes which are known to have occurred since that period, I made a rough estimate in 1887[1] that this time was distant from our own not more than 20,000 years. Observations by others, at home and abroad, have helped to confirm that estimate. Twenty thousand years is, at any rate, well within the estimates commonly made.

How long the Glacial Period lasted is a question still not satisfactorily answered—it certainly must have been one of great length, if one may judge by the amount of erosion that was accomplished on the *eastern* side of the Scottish watershed, where the precipitation from first to last mainly took the form of snow. But we do know that, although the valleys in the west were both deepened and widened by the ice, yet, as valleys, they existed long prior to the Glacial Period.

The time required for the excavation of these valleys by the joint agency of subaerial erosion and ice has next to be taken into account. We have no need to attempt an estimate of the thickness of rock removed during the Glacial Period itself—and almost none has been removed since. It will suffice if we take the average rate of lowering of the surface in general at 1 foot in 3000 years instead of 1 foot in 6000 years as is usually done, and then, in this case,

[1] "Ice-Work in Edenside," Trans. Cumberland and Westmorland Association, No. xi., p. 167.

assume that under the conditions most likely to have obtained in Pliocene and Pleistocene times, that denudation went on more rapidly than is usually the case. Bearing this in mind, we will assume that an estimated 1 foot in 2000 years for the erosion accomplished would be one certainly on the safe side. From the summit level of the Cuchullin Hills to the sea-level is now over 3100 feet. These hills consist of a kind of gabbro, a plutonic rock that, whatever its nature and origin, could not possibly have been formed within a short distance of the surface. One would be almost justified in regarding it as a rock of deep-seated origin, for even if it be, as I have suggested in the *Geological Magazine*, that this gabbro represents basaltic lavas re-crystallised by later intrusions, the metamorphism would still require that a considerable thickness of over-lying rock should have once covered it, and have since been removed. There are no exact means of arriving at an estimate of what that thickness was. But assuming that the Skye Volcano was of the same nature as, and had slopes as low as occur in, the volcanic mass of Hawaii, that alone would give us an elevation of its central portions of, at least, 8000 feet. In the period since the old volcano died out it has been trenched by rain, rivers, and ice to its very core. If this denudation has gone on at the moderate rate of only 1 foot in 2000 years, this rate gives us 16,000,000 as the time required for the formation of the valleys. The quantity of rock that has been removed since the close of the volcanic period can be shown by other examples to be enormous. Sir Archibald Geikie, in his well-known "Scenery of Scotland," refers especially to the excavation since that period of the great valley in which lies Loch Scridain in Mull; also to the extensive removal of volcanic material implied by the shaping of the Sound of Mull; and, further, to the evidence afforded by the dykes. For instance, referring to the dyke that crosses Loch Lomond and rises to near the summit of Ben Voirlich—and assuming that the particular dyke in question is of the same age as the volcanic rocks of Skye, Rum, Mull, etc.—he points out that, if the great valley in which Loch Lomond is situated was actually in existence at

the time the volcanic matter was being erupted, the dyke would have filled the valley instead of taking its present form. Hence, he points out, the valley must have been excavated since. Inferentially, therefore, any, or all, of the largest valleys that traverses the Highland plateaux may well have been formed since. No geologist fully cognisant of the vast and important physical and biological changes which can be shown to have taken place on the Continent and elsewhere since the close of the Miocene Period here referred to, can hesitate to regard the estimate of 16,000,000 of years as being well within the mark.

We have next to consider the time required for the building up of a volcano of the dimensions above referred to. Sir Charles Lyell many years ago pointed out that the rate of growth of a modern volcano would appear to be very much slower than has commonly been supposed. There are several reasons why this is the case. (1) The eruptions are intermittent, and are often separated by long periods of repose, during which the ordinary agents of denudation tend to transport much of the newly formed volcanic material in the direction of the sea. (2) Violent explosive outbursts occur, perhaps several times, in the life-history of most volcanoes. These result in the shattering of much of the rock material previously accumulated, and aid in its transfer by the action of the winds to areas many hundred times the area of the parent masses. (3) The lavas resulting from effusive eruptions usually take the form of narrow streaks, which are radial in respect to their crateral starting-points; other lava streams following these from the same crater rarely or never overflow the ridge formed by their immediate predecessors, but usually follow the line of lowest ground, which generally lies in another direction. Hence the lavas flowing from a summit crater take the form of radial streaks. To complete the circuit of the cone may require, in the case of a volcano of the form of Etna or Hawaii, many thousands of years. Hence the average thickness deposited in a century, taking the volcano all round, must actually be very small. Professor Lloyd Morgan, writing upon the subject of Geological Time (*Geological Magazine*, 1878, p. 204), regards

1 foot in 300 years as a fair average rate at which the growth of a volcano may be computed to have grown. No one who has carefully considered all the facts will regard this estimate as erring on the side of excess. We will therefore assume that the Skye Volcano, 8000 feet high over its central portion, grew at the rate of 1 foot in 300 years. Even at this comparatively rapid rate, and supposing that its growth went on without cessation, the volcano must have required 2,400,000 years for its completion. It is well known, however, that the growth of the volcanoes of that part was interrupted more than once or twice by long periods of quiescence, and we are therefore well within the truth in fixing the time at the rate just given.

For the purpose in view in the present address, it will be taken for granted that the Skye Volcano began to erupt some time in the Oligocene Period—many would think we should be quite justified in assigning a later date even than that to the commencement of the great volcanic episode. Prior to the Oligocene Period there was formed on the Continent several thousands of feet of the marine Nummulitic Limestone. Near Biarritz this rock is more than 3000 feet in thickness. The evidence for the whole of this being of later date than the Chalk, and of older date than the Oligocene strata, is admitted on all hands. Prior, therefore, to the first outbreaks of the Skye Volcano, and posterior in date to the Upper Cretaceous Rocks, occurred the marine episode referred to.

In dealing with the question of the rate at which rocks of sedimentary origin are being formed at the present day, we find ourselves at once face to face with the principal difficulty with which we meet in attempting to estimate the Age of the Earth. Of the rate of formation of terrigenous deposits we know as yet but very little. All one can say with tolerable certainty regarding the subject in general is that, as the greater part of the materials employed in their formation is carried seawards from the land by the agency of rivers, at a rate which is now (thanks to the labours of Tylor, Lyell, Croll, Geikie, and others) fairly well known, the rate of formation of a marine deposit of terrigenous

origin over a given area cannot much exceed the rate at which that material was wasted by subaerial agencies from an equal area of land. But when it comes to particulars, we are confronted with so many difficulties that it seems impossible, with the knowledge we can at present command, to make any statement regarding the rate of formation of any kind of terrigenous deposit, which can be regarded as much more than a speculation. Even if, in the case of any given river-discharge, we knew the rate at which the various sea currents were flowing, and we were sure of their direction in all cases, we should still have to take into account the fact that all delta-areas are areas of subsidence, and, further, that both the rate of subsidence and the rate at which the downward phase of terrestrial undulation which it represents is progressing, are factors of the utmost importance in working out a question of the kind before us. It is only, it seems to me, in the case of marine deposits of organico-chemical origin that we have any data which appear to be at all trustworthy in this respect. These, at any rate, are not now so much affected by local causes, and probably have not been so in the past. Moreover, the influence of diffusion throughout the whole oceanic area tends rapidly to equalise the percentage of mineral substances held in solution. Hence, for example, if a river draining a limestone district where there is a heavy rainfall, carries into the ocean at one part exceptionally large quantities of lime-salts, that quantity is soon equalised throughout the whole area of the ocean. In like manner, if, as in the case of the Pacific and Indian Oceans, the growth of coral reefs locally drains the surrounding water of its lime-salts at an exceptionally rapid rate, the balance is soon made good by supplies carried into the ocean from points hundreds or may be thousands of miles distant. Hence, ignoring coral-reefs as a form of limestone which is confined to the Post-Miocene Periods of the Earth's history, marine limestones appear to afford us the most satisfactory data upon which we can base our conclusions; as such, in the remainder of this address, I propose to employ them.

Mode of Formation and Rate of Growth of Marine Lime-

stones.—To be brief, one may say that the limestones of marine origin are formed almost entirely by the direct and indirect agency of animal and vegetable organisms, living and dead. These, as Irvine has shown, extract their carbonate of lime chiefly from the sulphate of lime present in sea-water, from which, ultimately, they convert it into the carbonate.

It will probably be generally admitted that all lime compounds in solution, both river-water and sea-water, were derived, primarily, from the silicates in eruptive rocks. From these they have been liberated by "weathering," and have been carried seaward in solution as bicarbonate. Probably nearly all limestones, except, perhaps, those associated with highly metamorphosed rocks of eruptive origin, are, so to speak, secondary products—the primary or initial stage of calcium being that of combination with silica in eruptive rocks. From both primary and secondary sources lime-salts are being carried seawards from the land by rivers at a rate which for the whole world is now fairly well known.

It has to be remembered that it is mainly from this source that marine organisms obtain the supply whence the hard part of their calcareous structure is built up. Supposing, for the moment, that this lime secreted by marine organisms is wholly derived from the supply furnished by rivers, let us see what the quantity possible to obtain per annum upon the sea-bottom would be. For this purpose we must first review Dr John Murray's figures relating to the relative areas concerned. Taking these from his latest papers, we have—

Total Area of the Globe, . . .	196,940,700 square miles.
Total Area of the Land, . . .	55,697,400 ,, ,,
Total Area of Inland Drainage, . .	11,486,350 ,, ,,
Total Area of Ocean Drainage, . .	44,211,050 ,, ,,

Area of Ocean Drainage to Area of entire Ocean, as 1 to 3·194.
Area of Ocean Drainage to Area of Calcareous Deposits, 1 to 1·173.
Area of Ocean Drainage to Area of Terrigenous Deposits, 1·62 to 1.

Aver. percent. of $CaCO_3$ in	27,899,300	sq. miles	of	Terrigenous Deposits,	19·
,, ,,	50,000,000	,,		Deep Sea Clays,	6·7
,, ,,	2,790,400	,,		,, Oozes,	4·
,, ,,	10,420,600	,,		Diatom Oozes,	22·96.

We have next to consider what evidence we have regarding the rate at which lime-salts are being supplied to the sea through the agency of rivers. Dr John Murray, in his "Total Annual Rainfall of the Land of the Globe, and the Relation of Rainfall to the Annual Discharge of Rivers," *Royal Scottish Geographical Magazine*, iii., pp. 65-77, gives a mass of data of the highest possible value in this respect. From Dr Murray's tables, Mr C. D. Walcott, in his "Address to Section E of the American Association for the Advancement of Science" (August 1893), has computed "113 tons as the total amount of matter in solution discharged into the Atlantic basin per annum from each square mile of area drained into it. Of this, 49 tons consist of carbonate of lime and 5·5 tons of sulphate and phosphate of lime." In a footnote Mr Walcott gives an abstract of Dr Murray's figures as follows:—"Total amount removed in solution per annum by rivers, 762,587 tons per cubic mile of river-water. Total discharge of river-water per annum into the Atlantic, 3947 cubic miles. Area drained, 26,400,000 square miles. Amount of carbonate of lime per annum, 326,710 tons per cubic mile of river-water; of sulphate of lime and phosphate of lime, 37,274 tons." Dr Murray's Table VII., *op. cit.*, p. 76, gives the proportion of the two latter salts as $Ca_3P_2O_8$, 2913 tons, and $CaSO_4$, 34,361 tons per cubic mile. Mr Wilbert Goodchild has computed for me the total quantity which these would represent if converted into $CaCO_3$. This comes to 4·143 tons from the phosphate and sulphate, which, added to the 49 tons of carbonate of lime, gives as the total 53·143 tons of carbonate of lime from each square mile of land surface per annum. The figures, it will be noted, are less than those given by Mellard Reade in his "Chemical Denudation in Relation to Geological Time," *Proc. Liverpool Geol. Soc.*, vol. iii., pp. 212-235 (1877). Further computation shows that, if we assume that 12·5 cubic feet of limestone go to the ton, this total quantity represents 664·3 cubic feet, which, if distributed over an area equal to that whence it has been derived, would, at the present rate of delivery by rivers, require 41,985 years for the accumulation of a thickness of a single foot.

The entire ocean area is to the area of ocean drainage as 3·194 to 1. If, therefore, the quantity of lime-salts carried by rivers into the ocean is converted into the solid form and left over the entire ocean area, the formation of a thickness of one foot of limestone would require more than 133,000 years.

There are, however, several causes which materially modify this result. One arises from the fact that the pressure of ocean water tends to dissolve calcareous organisms, beginning, as Professor Kendall has shown, with those which consist of aragonite, which are entirely dissolved before they descend from the surface-waters to a depth of 1500 fathoms, and dissolving those which consist of calcite as the depth increases, so that below 2900 fathoms hardly any reaches the bottom. This redissolved lime again enters into circulation, and becomes diffused through the areas adjoining. The area where this dissolution takes place, therefore, must be left out of account. It may be roughly estimated to form about one-third of the entire ocean floor. There are other areas of the ocean, again, where the low temperature of the surface-water is unfavourable to the growth of large numbers of the pelagic lime-secreting organisms. Over this area, therefore, the supply of lime-salts in the sea-water is but little drawn upon. Then, again, although coral-reefs do undoubtedly represent a drain of a large quantity of the ocean lime-salts over an area perhaps extending even thousands of miles around, yet the solution of the limestone so formed goes on both at the surface and at some depths below, so that a fairly large proportion must find its way again into diffusion soon after it is fixed. Littoral shell banks, again, although they do represent so much solid material abstracted from the sea-water, yet undergo solution to some extent. Add to these sources the percentage of lime-salts dissolved by the ocean waters from the coast-line itself, delivery from submarine springs, and the lime dissolved out of basic tuff which happens to fall into the sea, and we seem to have taken into account every possible source whence lime-salts can find their way into the ocean.

If we assume for the present purpose that the quantity of

lime-salts carried seaward annually by rivers is left in the solid form over one-third of the entire ocean area, and that the supply from the rivers is largely augmented by supplies derived from the possible sources mentioned, we still leave a large margin for the deposition of carbonate of lime from other—entirely unknown—sources, if, instead of 1 foot in 41,985 years, we regard it as accumulating now, and as having accumulated on the whole in the past, at 1 foot in 25,000 years.

If we estimate the thickness of the foraminiferal Nummulitic Limestone at only 3000 feet, this alone would require an interval of no less than 75,000,000 of years for its completion.

It is right to observe at this point that if there is any truth in the speculation that the atmosphere at past periods of the Earth's history contained even a slightly higher percentage of carbon-dioxide than it has now, the formation of limestone must have proceeded at even a slower rate than this. Also, if the ocean (as is supposed by many persons) formerly had a larger area relative to the land than it has now, the formation of limestone at the bottom of the sea in past times, so far from being more rapid than it is now, must have gone on at even a slower rate still. I shall therefore assume throughout this paper that 1 foot in 25,000 years is a fair rate to allow for the formation of marine limestones other than coral-reefs, with which geologists are but little concerned.

Summarising these figures, we have therefore for the duration of the Tertiary Period:—Time since the Glacial Period, 20,000 years; time for the excavation of the present land surface of the Western Island volcanic areas, 16,000,000 years; growth of the Skye Volcano, 2,400,000 years; time required for the formation of the Nummulitic Limestone, 75,000,000—total since the commencement of the Tertiary Period, 93,420,000 years.

Ninety-three millions of years may seem to those who are not fully acquainted with the succession of events that has taken place since the commencement of the Tertiary Period to be too extravagant an estimate to be for a moment seriously considered. With both geologists and biologists,

however, the case will be different. Each will be only too fully aware of the difficulty that is encountered in attempting to explain the vast and important changes in both the organic and the inorganic worlds during the period in question. If we may judge of the rate of changes in the organic world by the rate at which, on the whole, those changes have proceeded since the dawn of the Historical Period, then the time required for the evolution of the various forms of life that have peopled the globe since the commencement of the Tertiary Period must be vast almost beyond conception.

Again, if, as geologists, we have to interpret the changes in the inorganic world that have taken place in the past, we are bound to do so by reference to the changes that are going on at present, and this is especially true when we are dealing with the geological history of a period so comparatively recent as that just noticed. Not to interpret the recent past by the actual present would be to reject one of the surest and best principles of geological reasoning. Those who, considering all these points, may still be in doubt regarding the chronological importance of the Tertiary Period, may be reminded that in the Mediterranean basin alone an aggregate thickness of over 23,000 feet of strata, largely composed of marine limestones, was formed in this period, and that the very materials out of which much of our largest mountain chains have been shaped had not come into existence in the form of rocks until a late period of Tertiary times.

Finally, if it can be shown, on sufficiently good grounds, that the changes that have taken place in a period so recent as the Tertiary Period require for their accomplishment a measure of time so much in excess of that which, on mathematical grounds, we are told is all that can be allowed for the time since it was first possible for life to exist upon the earth, then, I would respectfully submit, there must be some serious error in the data upon which those computations were founded. I venture to think that such must be the case, and in the concluding portion of this address I shall make bold to point out where it seems to me that some part of the error may possibly have crept in. In the meantime, geologists will probably agree with me in thinking that we

may disregard the view I have referred to regarding the Age of the Earth. We may again advance, though most of my fellow-thinkers will agree with me in taking the lesson we have learned seriously to heart, so that when we do again advance, we may do so with much more cautious steps than many of us took before Lord Kelvin appeared at our head and gave us the order to countermarch.

Relation of the Tertiary Rocks to those of the Cretaceous Age.—In the Mediterranean region, and in the adjoining parts of Asia, no line can be drawn between the limestones of Eocene age and those referred to the Cretaceous Period. But in Western Europe the difference between the Eocene fauna and that of the Chalk is generally regarded as so great as to imply that a long interval of time elapsed between the formation of the two deposits. I shall endeavour to show that this difference is by no means as great as has been generally assumed. Moreover, an examination of almost every known section where the Lower Eocene Thanet Sands lie upon the Chalk, convinced me, over thirty years ago, that there is no trace whatever of any physical break between the two, or, at any rate, no more than might be expected to accompany a change of conditions from the warm surface-currents and the deep water of the Chalk sea to the colder surface-water and lesser depths of the sea in which the Thanet Sands were deposited. I therefore think it safer not to take into account, in the present connection, any interval of time which may possibly have elapsed between the close of the Chalk Period and the commencement of that during which the Eocene Thanet Sands were formed. The commencement of the period when the Nummulitic Limestone was formed immediately followed the close of the Cretaceous Period, and was not separated from this by any break.

Time required for the Formation of the Chalk.—The true measure of time required for the formation of the rock of any given geological period should be estimated with reference to the *maximum* thickness known to occur between an upper well-defined stage, characterised by life-zones whose contemporaneity over a larger area has been well put to the test by many observers, and a lower stage equally well characterised

by its fossils. I would refer to the relation of the Moffat Terrane, with its graptolite zones, to their chronological equivalents in North Wales; or to the Lias, with its Ammonite zones, in illustration of what is meant here. If possible in making comparisons, sedimentary rocks of one petrographical type—such as there is reason to believe must have been formed at nearly the same rate through all geological periods—should be uniformly employed. Marine limestones are certainly the best for this purpose, except where, as in the case of some few rocks formed since Eocene times, these may happen to consist of true coral-reefs. The Chalk appears to me to be a typical deposit of this kind, as it was certainly formed in deep water, and at a rate sufficiently slow to admit of its including records of a long succession of changes of life—longer, I should think, than the whole of the period that has elapsed since its formation ceased on this part of the earth's surface.

In the neighbourhood of Southampton, and again near Norwich, the Chalk exceeds 1100 feet in thickness. On the east side of the North Sea it is even thicker than that. From bottom to top, it is almost entirely free from admixture with rock material of purely terrigenous origin, and its general petrographical character is that of a deposit formed under much the same conditions as the foraminiferal oozes of the ocean of the present day.

If we assume, as was done in the case of the Nummulitic Limestone, that 1 foot in 25,000 years fairly represents the rate at which limestones are now being (and have always been) formed, then, not taking into account any interruption of deposit, a thickness of 1100 feet of Chalk requires 27,500,000 years.

If this is the case, we need hardly marvel at the gradual disappearance of the Cephalopoda of the Chalk, nor at that of the great reptiles. According to the view here set forth, the Ammonites and Belemnites died out almost entirely within the Cretaceous Period itself. Only one Ammonite is known to survive to the period represented by the topmost bed of the Chalk, and the great reptiles appear, one by one, to have vanished from the face of the earth at an earlier period even

than that. As for the lower Invertebrata, it cannot be too strongly insisted upon, as I pointed out many years ago, that the Gasteropoda and Lamellibranchiata of the beds next below the Chalk are very closely related to those which reappear in the Lower Eocenes, and especially in the Thanet Sands. Need I repeat that the same is substantially true of both the fishes and the plants?

Upper Greensand and Gault.—The base of the Chalk graduates downward in places into a glauconitic sand similar to that which is now being slowly accumulated in deep water off the east coast of Africa. This, in turn, graduates downward into the fine-textured marine clay, the Gault. The numerous biological changes to which the fossils in these rocks testify, necessarily denote long intervals of time. In the absence of any reliable data, we may perhaps assume that these rocks, as a whole, were formed at the rate of 1 foot in 5000 years. The Gault is 300 feet in thickness (or more), which, at the hypothetical rate suggested, gives us an interval of 1,500,000 years.

An important unconformity occurs at the base of the Cretaceous Series—one which implies so vast a lapse of time that it would appear to be desirable here to consider, first of all in general terms, to what conclusion phenomena of this kind are likely to conduct us.

Chronological Value of Unconformities. — There exists amongst geologists a considerable diversity of opinion regarding the time-value which should be put upon unconformities. On the one hand, there are those geologists who regard every unconformity as representing an interval of time which, in every case, is proportional to the thickness of strata missing, which interval of time they think should be added to the time required for the deposition of the quantity of rock removed. On the other hand are those who are disposed to regard all unconformities in the light of mere local, and purely accidental, phenomena, to which, in estimating the Age of the Earth, no importance whatever need be attached. There are others again, who, in spite of perfectly clear field-evidence, will persist in either inserting hypothetical unconformities between two adjoining groups

of strata whose fossils happen to differ materially (as, for example, between the Chalk and the Thanet Sands, or between the Dyas and the Trias), or, otherwise, will ignore with equal persistence the time-value of an extensive unconformity such as that between the Lower New Red or Dyas and the Carboniferous and other rocks beneath, merely because a few fossils of low biological grade happen to have a sufficiently wide range in time to extend across the unconformity.

That unconformities have very different time-values in different cases, no field-geologist would be prepared to deny. All he would say regarding the general question is that each case must be judged entirely on its own merits, and that due regard must be paid in each case to both the physical and the biological aspects of the question. All unconformities must necessarily be, in one sense, local phenomena, and there must be, in every case, strata of some kind or other which have been formed in one part during the interval when waste and destruction were going on in another. This is only another way of stating the fact that the deposition of strata must have gone on continuously, and absolutely without break, over one part or another of the earth's surface, from the very beginning of its geological history down to the present day. It is only that the areas of deposit have gradually changed their positions, and that areas which at one time have been areas undergoing depression, have gradually changed phase and have become for a time areas of upheaval. There are many geologists who are of opinion that movements of these kinds have at one time or another affected every part of the earth's crust—in the course of long ages changing continental areas into oceans, or oceanic areas into land. However much geologists may differ upon this particular point, they are all agreed that earth-movements take the form of undulations. They would probably also mostly agree that these undulations differ widely in different cases in their amplitude, in their wave-length, and in their frequency. If, bearing these points in mind, they would take into account the fact (to which fuller reference will be made further on) that

these terrestrial undulations progress, and roll, like great terrestrial tide-waves, from one part of the earth's surface to another, in the course of long ages, much of the difficulty that has been experienced in dealing with the subject of unconformities would no longer be felt. In each case, where it is possible to do so, we have to determine the amplitude, the wave-length, the locus of each wave-crest or wave-sinus at any particular time, the frequency of the undulation, and, finally, the direction of propagation. Geological evidence in a few cases supplies us with information upon one or more of these points, sometimes to an extent sufficient to warrant us in coming to fairly definite conclusions regarding the chronological value of particular unconformities. In other cases the information is very scanty, and we can only form our conclusions upon this point after studying a considerable number of collateral facts.

In pursuing the study of unconformities, there are many pitfalls into which the unwary inquirer may readily slip, and in this matter perhaps more than in most other geological subjects it is necessary to proceed with the greatest possible caution. In the case of one unconformity which will be considered in some detail presently, a particular stratum can be shown to lie across, or overstep, the edges of various strata whose collective thickness amounts to several miles. In a case of this kind we have to be quite sure (1) that the collective thickness referred to actually represents the thickness of strata which are known to have covered the lowest stratum overstepped at some time prior to the deposition of the overstepping stratum. (2) We have to assure ourselves that the unconformity in question is not wholly or in part contemporaneous, *i.e.*, whether in the case referred to the denudation of the strata did not commence at one part, while the deposition of the higher and newer strata of the same series went on in another—the areas of denudation and deposition lying within the area now overstepped by the unconformable bed. (3) We have further to assure ourselves that the unconformity in question belongs wholly to the period following the close of the formation of the highest bed overstepped, or whether it may with more

probability be distributed over more than the one period. (4) And finally, we have to take into account both the nature of the denuding agency and the relative destructibility of the strata removed. If we are sure upon all these points, we may make our calculations with more or less confidence. As an illustration of what is meant, it may be mentioned here that the Upper Cretaceous Rocks of Britain (and of Western Europe in general) lie upon the upturned and denuded edges of strata, extending from the summit of the Neocomians across the whole of the Jurassic Rocks, the New Red, the Carboniferous, the Devonian, and even on to rocks in Scotland which are almost certainly of Pre-Cambrian Age. Over all these strata, collectively many thousands of feet in thickness, the Upper Cretaceous Rocks lie with an evenness of base which is little short of marvellous.[1] Yet we must be on our guard against supposing that the whole thickness of these strata was actually removed by denudation at this period. All that can confidently be stated is that the edges of the strata were planed to their present even form just before the Cretaceous strata were laid down. The total thickness of rock that can safely be regarded as having been removed by denudation which followed the Jurassic-Wealden Period and preceded the Neocomian and Cretaceous, is the aggregate thickness of the strata extending downward from the top of the Wealden to the base of the Upper New Red. We can easily satisfy ourselves that, traced westward along the southern parts of England, the Upper Cretaceous strata overstep the edges of the whole of the strata which are enclosed between the summit of the Wealden Rocks and the base of the Inferior Oolite. The Cretaceous Rocks of course lie upon strata of Neozoic Age much older than that—but we can be quite sure that the thickness referred to did actually at one time exist, and was removed by denudation prior to the deposition of the strata that succeed. The total thick-

[1] I have long taught in my lectures that the peneplain of the Highland mountains, and of the mountain tops in the North of England, is the "modified descendant" of this Pre-Cretaceous plain, upheaved, and re-exposed by subsequent denudation of the Cretaceous Rocks.

ness of strata referred to consists of 2000 feet of the Wealden and 2400 feet of the Jurassics. This estimate does not take into account the thickness of the Lias (1340 feet) nor that of the New Red (fully 2500 feet), because there would appear to be some evidence that these strata were contemporaneously denuded during the formation of the later-formed rocks. To these rocks so removed we might well add the thickness of the Lower Greensand; but as there appears to be still some doubt in the minds of a few geologists regarding the physical relationship of these rocks to the strata above and below, I have thought it better in this connection to leave them out of account.

Now if we are to go upon the principle that we must, as far as possible, interpret the past by the present, we are justified in assuming that after the Wealden strata were formed, and before the Gault was laid down, strata to a thickness of 4400 feet were tilted and denuded. If this denudation went on at the rate of 1 foot in 3000 years, this implies an interval of time of 13,200,000 years. Further investigation may, possibly, lead to this estimate being somewhat modified; but, in the meantime, what other estimate can be made? If we abandon the principle of interpreting the past by the present, we shall be ignoring one of the foremost principles upon which all modern geological reasoning is based. I would much prefer to state my conclusions arrived at after due consideration, let them be in accordance with the beliefs at present in fashion or not, rather than make any departure from moderately uniformitarian principles.

We now retrace our steps, and consider here the *Time required for the Formation of the Lower Greensand.*—Strata of this age occur between the Wealden and the Upper Cretaceous Rocks in the south-east of England. They consist largely of glauconitic sands of undoubted marine origin, together with marine clays, and beds of chert, which are largely composed of sponge spicules. Whether regarded from a physical or from a biological point of view, these strata must have taken a long time to form. But in the absence of reliable estimates, I shall be content to assume that they were formed at the rate of 1 foot in 3000 years. This, at a

thickness of 800 feet, gives 2,400,000 years, an estimate, again, which palæontologists, taking the life-history of the period into account, will probably regard as far too small.

Wealden-Jurassic Series.—Prior to the great Pre-Cretaceous unconformity, there was formed in the south of England more than 5700 feet of strata without any break—to wit, Wealden 2000, Oolites and Lias 3700. These largely consist of limestones, which show every sign of having been very slowly formed. It has been said that some of the limestones are simply old coral-reefs, and on that account it has been assumed that their rate of formation has been comparatively rapid. But the important fact seems to have been overlooked that the Jurassic Limestones do not occur as great upstanding masses which end off all round with great abruptness, but, on the contrary, they are distinctly well-stratified deposits, showing every sign of having been laid down upon the sea-bottom in precisely the same manner as the majority of other limestones; and, like these, are remarkably persistent over large areas. Corals occur in them in abundance; but there is an important difference between a limestone full of corals and a coral-reef. It may well be doubted whether the reef-building habit amongst corals can be traced back in time farther than the Miocene Period at the farthest.

Taking the Jurassic-Wealden series as a whole (and including the *marine* Wealden of the south of France), more than one-third of the entire thickness (or 2000 feet) consists of limestone. Assuming, as before, that each foot of this marine limestone took 25,000 years to form, the time required for this alone amounts to 50,000,000 years. We have to add to that the time required for the marine clays (which may be regarded as constituting another 2000 feet), 1 foot in 3000 years, to put it at the highest rate, another 6,000,000 years. To these add the time required for the formation of 1700 feet of sandstones. These Jurassic Sandstones I should be disposed to regard as having been formed at the rate of 1 foot in 2000 years, which makes an additional 3,400,000 years. This, in all, makes the period required for the evolution of the many successive changes of animal and plant life, which are so

conspicuous a feature in the geology of the Jurassic-Wealden period, 59,400,000 years.

The New Red Rocks (Dyas and Trias).—At several localities in Britain, as is well known, a considerable thickness of rock, formed mainly under desert conditions, underlies the Jurassic Rocks proper. Their upper limit is marked by the (Marine) Rhætic Rocks, which contain a very well-defined fauna, and which graduate upward into the base of the Jurassic Rocks. Their lower limits are extremely variable—perhaps on account of their having been formed under terrestrial conditions—perhaps partly on account of more-than-usually-local flexures of the subjacent surface arising through differential subsidence. The aggregate maximum thickness may be fully 4000 feet; yet the higher members overlap in succession every one of the lower in one part or the other of Britain. Wherever the series exists, it is practically one conformable series from the top to the bottom. On the other hand, the base lies in one part or another with a violent unconformity upon every rock older than itself.

Low down in the series occurs, in places, a band of Magnesian Limestone, whose fossils, and especially the Invertebrata, show a certain affinity with those of the Carboniferous. This affinity, however, is by no means as close as was believed up to a few years ago, as many fossils supposed to have come from the Dyas really came from stained rocks of Carboniferous age. The fossils of the Magnesian Limestone, whatever their affinities may be, are sufficiently marked in character to enable one to trace the English Magnesian Limestone, by the aid of its fossil contents, far to the east of the British Isles. On the Continent, therefore, we can trace the upper limit of the New Red by means of the Rhætic strata into central Europe, and we can follow the Magnesian Limestone by the same clue almost as far. Important changes in the nature of the beds between these two platforms set in; and in place of a series of desert-formed rocks we find, in the Tyrol, thick masses of Marine Limestone. I have before suggested that we should employ as far as possible a uniform system in comparing strata of different ages, and should take every-

where as our type-deposit a marine limestone, and name the rocks in question from the locality where the marine calcareous type is best seen and most fully developed. I propose, therefore, that we should employ the name TYROLIAN for the Trias, just as we use DEVONIAN as the type form of the strata that were deposited while the Old Red Sandstone was being laid down. I should like to go further in this same direction. The Lower New Red (Dyas, or so-called "Permian") also takes on a marine facies in the Mediterranean region, being represented there by a considerable thickness of marine limestone, which in Sicily, near Palermo—the *Panormus* of the ancients—has yielded a most interesting and extensive set of fossils, including many Ammonites. I would suggest that the name PANORMIAN might fittingly be applied to this, the type-deposit of the same age as the Lower New Red, Dyas, or "Permian." So far as we are concerned in the present inquiry, the chief point of interest and importance is that the New Red Series is represented on the Continent by a thick series of marine limestones (the Tyrolian and Panormian Rocks), which fill up the *later* part of the vast chronological hiatus between the Carboniferous Rocks and those of Jurassic age. The abundance and variety of Ammonites in the Panormian, shows that we are dealing with the upper part of the intermediate series; but as there is just a possibility that the Panormian Rocks may represent not only our own Lower New Red or Dyas, but also represent in time part of the gap to be presently referred to, I propose for the present purpose to leave it out of account, and to compute the time with reference only to the marine limestone of the Rhætic and Tyrolian series. These are said to be "several thousands of feet" in thickness; but beyond this vague estimate there appears to be well-authenticated measurements of more than 3500 feet of marine limestone, largely made up of marine lime-secreting algæ. Taking the same figures as before, 3500 feet of limestone at 1 foot in 25,000 years, gives us 87,000,000 years. Again would I remind the reader of the enormous biological changes which took place in the interval —the development of the Anomodont reptiles from the

Amphibia, the evolution of the Ammonites, in short, the incoming of the new order of life, which is so marked a feature of the palæontology of these rocks, and which has led systematists to make the great dividing line between the Deuterozoic Rocks and those of Neozoic age coincide with the base of our New Red.

It is, of course, obvious that whatever time was required for the formation of Tyrolian Rocks, the same time must be required also for their British equivalents, the thin marine Rhætic Rocks and the 2500 feet of desert rocks which form the Upper New Red or Trias. Regarding the Panormian and its British equivalent, the Lower New Red or Dyas, I can offer no estimate; but as the sandstones of the Lower New Red were evidently formed under the same conditions as those of the Upper, we have to add on some unknown figure to the above. This, in the present state of our knowledge, we may here leave out.

Unconformity below the New Red in Britain.—There can be no reasonable doubt that the base of the Upper New Red in Britain is contemporaneous with the base of the Upper New Red—and therefore of the Tyrolian—on the Continent. We have next to consider the relation of this base to the older rocks in Britain. Briefly, it may be stated to be one of considerable and extensive unconformity. Not only were the older rocks folded, contorted, and faulted, but they were afterwards subjected to enormous denudation. This certainly happened in the interval following the close of the Upper Carboniferous Period, and preceded the deposition of the New Red itself. In the Bristol area the Upper New Red oversteps the denuded edges of the faulted and highly-disturbed rocks of Carboniferous age, as well as the whole of the Upper Old Red. There can be no question in this case of either non-deposition or of contemporaneous upheaval and denudation, as the Carboniferous strata are repeated on either limb of several anticlinals, and their strike is perfectly independent of that of the New Red. In this case, therefore, we have clear evidence of the removal by denudation of 15,000 feet of strata after the formation of the Upper Carboniferous Rocks, and before the deposition of the

Upper New Red. The evidence afforded by the Bristol area does not stand alone in this respect, but is abundantly confirmed by the relation of these rocks to each other in many different areas.

More than that, in Devonshire the New Red Rocks overstep not the whole of the Carboniferous, but most, if not the whole, of the Devonian Rocks as well. Possibly this latter feature may be attributable to an unconformity between the Upper Old Red and the Devonian Rocks, similar to that in Ireland between the Upper Old Red and the Glengariff Grits, and in Scotland between the Upper Old Red and all the rocks older than itself, including the Orcadian Old Red and the Caledonian Old Red.

If we assume that this unconformity in the Bristol area represents the removal of 15,000 feet of strata at the rate of 1 foot in 3000 years, that adds 45,000,000 years to our chronology.

Time required for the Formation of the Carboniferous Rocks.—Speaking in very general terms, the Carboniferous Rocks of England and Wales may be said to be divisible into two sections—Upper Carboniferous, which in Britain is certainly a terrigenous deposit, formed at no great distance from the land, probably as part of a delta; and Lower Carboniferous, which in England, Wales, and Ireland, is certainly in the main a marine deposit formed in moderately deep water in the southern parts of the kingdom, and in shallower water in Scotland. In some districts where fossils have not yet given the clue, there exists a little uncertainty as to where the dividing-line between the Upper and the Lower division should be drawn. In other districts, both physical and palæontological evidence point to the existence of an unconformity between them, as there is a very marked discrepancy between the vertebrate faunæ of the two divisions,[1] and the discrepancy between the fossil floras is not less pronounced.[2] For the present purpose, it will suffice to regard the rocks of the Severn basin as fairly typical of the whole series, and to base our estimates upon the facts we can glean from a study

[1] Traquair, Proc. Roy. Soc. Edin., vol. xviii. (1890), p. 387; Geol. Mag., Dec. iii., vol. i., pp. 115–121.

[2] Kidston, Proc. Roy. Phys. Soc., 1894.

of the Carboniferous Rocks of that part. In the area referred to, the Upper Carboniferous Rocks (including under that term, for the present purpose, all the rocks from the highest remaining Coal-Measures to the top bed of the Carboniferous Limestone) are estimated to be fully 12,000 feet in thickness. These consist of alternate beds of sandstone, shale, fireclay, and coal. In dealing with these strata, we are forced to confess that we have not, and probably may not obtain yet for many years, any reliable estimate of the several rates at which delta deposits are at present being laid down. The most that can be done in the present state of our knowledge is to form an estimate from the "Challenger" maps of the ratio between the superficial area occupied by the purely terrigenous deposits now in process of formation, to compare this area with the area of the land whence drainage finds its way seaward, and then on this basis compute the proportion between the area of deposit and the proportion of material mechanically carried seaward by rivers. In the case of lime-salts, a question of this kind is simplified by the fact that, owing to rapid diffusion of matter carried in solution, especially lime-salts, an excess of these poured into the ocean by the rivers of one area is rapidly equalised by diffusion over the entire ocean area. An average rate, computed from observation made upon several rivers in different parts of the globe, therefore holds good for the whole. With terrigenous deposits the case is widely different. No diffusion worth considering appears to take place. On the contrary, each river has its own rate of deposit, which again, unlike the rate of diffusion of solutions, may be very different now from what it was at the same spot in former times, when different conditions obtained. Further, the matter is complicated by oscillations of level of the land, and by the fact that, unlike calcareous deposits of marine origin, marine terrigenous deposits tend to be more or less lenticular in form.

A rough estimate, however, based upon a comparison of ocean-drainage areas to the area of the terrigenous deposits in each case (the volume being yet unknown), gives us the following:—In the Indo-Chinese area the superficial area of the terrigenous deposits is to the drainage area about as

two-thirds to one. In the Eurasian Atlantic drainage area the extent of the terrigenous deposits is to that of the oceanic drainage area also as two-thirds to one. On the other hand, the North American Atlantic drainage area gives rise to a much smaller fringe of terrigenous deposits, which form certainly less than half the area from which their materials are derived. In the South American Atlantic drainage area the terrigenous deposits occupy not more than one-third of the area of the land. In this case, as in the case of Africa, the proportion appears to be smaller than it really is, because the terrigenous deposits fall rapidly into deep water, and their superficial extent is therefore less in proportion to the thickness than it might otherwise be. As pointed out above, we can have no definite estimates of the rate of formation of delta deposits (not, at any rate, in terms of feet per century) until we know the amount and nature of the material transported, the rate of subsidence, and the strength and direction of the marine currents outside the delta. What we require to know is not so much the *area* alone which is formed in a given delta in a given time, as the *thickness* which is deposited in that time.

Dr John Murray's figures and maps give us as the total area of ocean drainage 44,211,050 square miles, and 27,899,300 square miles as the approximate area of terrigenous deposits. This is in the proportion of rather more than one and a half of drainage area, or area of denudation, to one of the ocean area over which terrigenous deposits are being laid down. This would seem at first sight to imply that the deposition of strata goes on half as fast again as denudation, and that a foot and a half of strata is laid down upon the sea-bed in the same time that is required to strip one foot of rock from the general surface of the land. That this is far from being the case will be evident when we consider that a large part of the sand and loam transported seawards from the land finds a resting-place close to the land itself. It is readily conceivable that loam (which is a mixture of fine sand with a small percentage of clay) should be laid down at the rate, say, of 1 foot in 2000 years. The finer clay, however, drifts far and wide before it subsides, and we should

probably not greatly err in estimating the rate of formation of the clays and shales of the Upper Carboniferous Rocks if we set that rate at 1 foot in 3000 years. Now, the Upper Carboniferous Rocks of the South Wales Coal-field are said to be 14,000 feet in thickness. Of these, about half the thickness may be set down as sandstones, and the remainder of clays of one kind or another, together with coal-seams. Seven thousand feet of sandstone, if formed at the rate of 1 foot in 1500 years, give us 10,500,000 years; while 7000 feet of clays, at 1 foot in 3000 years, give an additional 21,000,000. To this we have to add the time required for the formation of the 105 feet of coal, which is said to be the aggregate thickness found in the Upper Carboniferous Rocks around Manchester.

In regard to these one may remark, it may be possible to "hurry up" in estimating the rate at which sandstones and a few other deposits have been formed, but when we are asked to do this in connection with either limestones or coals, the case appears to me to be very different. One has to remember that all vegetation derives its fixed carbon from the atmosphere alone, and that it does this under the combined influence of solar energy and its own vital force. The proportion of carbon-dioxide at present existing in the atmosphere is very small, ranging from an average of ·04 % to a maximum of ·10 %. A larger percentage than this latter is said to be detrimental, rather than conducive, to the growth of vegetable life. The supply of carbon-dioxide, which balances the demand made by the formation of limestones (in every cubic foot of which 16,000 cubic feet of carbon-dioxide are locked up) and of coals (of which carbon constitutes from 60 to 90 %), is met partly by the products of animal respiration, partly by the products of the decomposition of organisms, both vegetable and animal, but mainly from exhalations from volcanic sources. In the formation of eruptive rocks, a large quantity of carbonates of lime and other bases must be constantly passing back into their initial stage, that of combination in the various silicates. In this process carbon-dioxide is now, as it must always have been, liberated in considerable volumes. Bischoff estimates that 1,855,000,000 cubic feet of this

gas rise annually from the vicinity of the lake of Laach alone, and it is almost certain that quantities equally large are given off from many other volcanic areas, both active and quiescent, elsewhere. This is mentioned here as an answer to one objection which has been often advanced against basing an estimate of the Age of the Earth upon the rate of denudation now taking place; the ground upon which the objection was founded being that the quantity of carbon now locked up in our coals and limestones must formerly have existed in the atmosphere over and above the percentage which is now present. This excess (if present) would, as has been very rightly pointed out, most materially accelerate at least the chemical disintegration of rocks, and thereby indirectly increase also the rate of deposit. But for the reasons given here and above, I agree with those who think that we are not justified in assuming the existence of any such excess above the percentage just given, *i.e.*, an average of ·04 %, ranging to a maximum of ·10 %.

Many coal-seams are known to consist largely of spores and spore-cases of Lepidodendroid origin—the actual plants themselves constituting but a small percentage of the mass. This is not the place to enter into a discussion of the precise conditions under which the majority of coal-seams were formed,[1] but on any view of their origin this fact is one of the many that points to their extremely slow growth. Mr Kidston, in his Address to this Society in 1894, has shown us in the clearest possible manner that it is very far from being the truth that the same species of plants existed all through the Carboniferous Period, and therefore gave rise to the various coal-seams that occur from the middle of the Lower Carboniferous Rocks up to the highest coal-bearing horizon. There was, on the contrary, a gradual replacement of one species by another, which, as the physical conditions remained the same throughout all the subdivisions of the periods when coal-seams were being formed, points in the most unmistakable manner to the lapse of enormous intervals of time. What the actual time required for the formation

[1] "Some of the Modes of Formation of Coal-Seams," J. G. Goodchild, Proceedings Royal Physical Society, vol. x., p. 97.

of a foot of coal may be has been variously estimated—no two persons agreeing even approximately. Professor Huxley ("Formation of Coal," *Contemporary Review*, 1870, p. 627) suggests a possibility of it being about 1 foot in 500 years. Boussingault estimates (*Smithsonian Report for* 1857, p. 138) that luxuriant vegetation at the present day takes from the atmosphere about half a ton of carbon per acre annually, or 50 tons carbon in 100 years. Fifty tons of carbon of the specific gravity of coal (about 1·5) spread over an acre would make a layer about $\frac{1}{3}$ inch (1 inch in 300 years, 1 foot in 3600 years). Professor Phillips "Life on the Earth," p. 133, calculating from the amount of carbon taken from the atmosphere, as determined by Liebig, considers that if it were converted into coal, with about 75 % of carbon, it would yield 1 inch in 127·5 years, or 1 foot in 1530 years. Humboldt's estimate is 1 foot in 1800 years. Croll estimates it at 1 foot in 1600 years.

These figures are given on the assumption that coal is a purely subaerial deposit. In studying the mode of occurrence of coal-seams in the field, I have, however, come to the conclusion that a fairly large percentage of coal-seams of Lower Carboniferous age represent the mean term of a series of rocks which have marine shale at one end and marine limestone at the other. I should infer from these facts that the rate of formation of the coals in question was intermediate in age as the seams are intermediate in geological position—between that of finely laminated marine clays on the one hand and marine limestones on the other. These Lower Carboniferous coals of submarine origin are marvellously persistent in both lithological character and geographical extent, and I fail to see any reason why they should not be fair representatives of the great majority of coal-seams of all other ages.

Whether many will agree with me or not in these conclusions is not very material, but the facts as they appear to me warrant us in assuming that the rate of growth of coal-seams went on at the rate of somewhere between 1 foot in 3000 years and 1 foot in 6000. If we take the rate at the lower of the two estimates, 105 feet of coal, which is

the aggregate thickness of the coal-seams in the Upper Carboniferous Rocks near Manchester, gives us 315,000 years. This takes no account of any intermittent action during the formation of these coals, nor does it take into account the fact that north of Yorkshire all the Upper Carboniferous Coals belong chiefly to the Millstone Grit, or at the very highest to the Lower Coal-Measures of the Manchester and Bristol section. An additional 40 feet of coal would therefore need to be taken into account.

Recapitulating these figures, we have—time required for the formation of 7000 feet of sandstone, at 1 foot in 1500 years, ...	10,500,000
7000 feet of argillaceous beds, at 1 foot in 3000 years, ...	21,000,000
105 feet of coal, at 1 foot in 3000 years, . .	315,000
Total, Upper Carboniferous,	31,815,000

Possible Unconformity at the Base of the Upper Carboniferous Rocks.—When I joined the Geological Survey in 1867, the present Woodwardian Professor (then Mr T. M'K. Hughes) instructed me, while mapping the Carboniferous Rocks of north-west Yorkshire, to keep a look-out for evidence of unconformity at the base of the Millstone Grit, *i.e.*, at the base of the Upper Carboniferous Rocks. After a few years field-work at these rocks, evidence began to be apparent; and I am now convinced that, in the dales of north-west Yorkshire, and in the area extending thence towards Craven, the Ingleboro Grit (the bottom bed of the Upper Carboniferous Rocks) does lie across, or overstep, the higher beds of the Yoredale Rocks, which form the uppermost member of the Lower Carboniferous Rocks. Many facts, which seem to me otherwise difficult of explanation, are easily accounted for on the supposition that this unconformity extends over a wider area still. Palæontological evidence is not wanting in confirmation of this view. Dr Traquair has repeatedly emphasised the fact that the fish fauna of the Upper Carboniferous Rocks has hardly any species in common with that occurring in the Lower Carboniferous. This becomes a striking and significant fact

when it is realised that the physical conditions under which most of the Lower Carboniferous Rocks of Scotland were formed were identical with those under which the Upper Carboniferous Rocks of the same part of the British Isles were accumulated. Mr Robert Kidston is equally emphatic upon this point in regard to the plants.[1] We cannot leave this unconformity out of account, and yet there are no means of forming even an approximate estimate of its duration.

Lower Carboniferous Rocks.—In dealing with these, I shall adhere, as before, to the plan of estimating the time by that required for the deposition of the maximum thickness of marine limestone found during the period—partly because we should, I think, take the marine limestones of each period on the typical or standard deposit; partly because we may safely assume that when we are dealing with marine deposits of organico-chemical origin like these, the rate of growth must have been the same (or nearly the same) in the case of at least all the limestones that have been formed from those of the Cambrian Period down to the Foraminiferal ooze of to-day.

The Lower Carboniferous Rocks of the Bristol and other areas consist of 2500 feet of marine limestone. This, at the rate of 1 foot in 25,000 years, would require 62,500,000 years.

Omitting any reference to the Lower Limestone Shales—which may be represented in Edinburgh by the greater part of the 2000 feet of the red and green beds below the volcanic rocks of Arthur's Seat, we have as a grand total for the Carboniferous Period, Upper and Lower, 94,315,000 years.

It has to be borne in mind that the top of the Coal-Measures is probably not left anywhere in Britain. Possibly it may be represented on the Continent by some of the beds called Permian in Bohemia.

Upper Old Red.—In places the Lower Carboniferous Rocks graduate downward into the true Upper Old Red—the Lower Limestone Shales forming the passage beds from the one to the other. This is the case, for instance, near Sedbergh in

[1] See the Vice-Presidential Address before the Royal Physical Society in 1894.

Yorkshire, near Bristol, at various localities in Ireland, at Copeth ("Cockburnspath") on the Berwickshire coast, and, lastly, in the city of Edinburgh. In other places it appears to me that there is evidence of a certain amount of unconformity between the two formations—not on palæontological grounds alone, but also on physical. The Lower Carboniferous Rocks of Cumberland, for example, of East Fife, probably also of the Pentlands, appear to me to lie trangressively across the denuded ends of the older rocks, including the Upper Old Red, in a manner suggestive of something more than contemporaneous erosion. Messrs Lapworth and Watts ("Geology of South Shropshire," p. 331) refer to facts of much the same kind in that district. Although the unconformity may not appear to be great, it certainly coincides with the final disappearance of the very remarkable groups of fishes which characterise the Old Red. Personally, I doubt whether the geographical change from that of desert conditions and inland lakes to marine conditions affords altogether a satisfactory explanation of the phenomena. Lapse of time is a factor of equal importance, and all the evidence to the contrary in this particular case has completely broken down with advance of knowledge.

From the Upper Old Red Sandstone, petrographically considered, we can draw no conclusions of any value respecting the time implied in the formation of these rocks. But the researches of Dr Traquair have made known to us the fact that palæontological zones exist in the Upper Old Red as in other formations.[1] It is difficult to see how this could arise unless the formation of the rocks in question occupied a very long time.

In the absence of definite data, I am reluctantly compelled to omit this from the calculation. But, as will be seen presently, the marine Devonian of the Continent is probably contemporaneous with not only the lower parts of the Old Red series, but with the Upper Old Red as well, so that we shall count it in another connection.

[1] "Extinct Vertebrata of the Moray Firth Area," in Harvie-Brown and Buckley's "Vertebrate Fauna of the Moray Basin," vol. ii. Edinburgh, 1896.

Unconformity at the Base of the Upper Old Red.—In the English Lake District the Upper Old Red lies across, or oversteps, the ends of strata fully as much as five miles in thickness.[1] In Scotland it lies unconformably across all the strata older than itself. At the Old Man of Hoy, for example, the Upper Old Red forming the "Old Man" lies in a nearly horizontal position on the ends of beds very high up in the Orcadians, which are tilted, Dr Heddle tells me, at angles of 30° to 35°. Within a short distance the same Upper Old Red oversteps fully 7000 feet of the Orcadian Rocks there. I very strongly suspect, as already hinted above when discussing the New Red, that this same unconformity of the Upper Old Red upon the older rocks will be found, on closer examination, to extend into the areas occupied by the Devonian Rocks of Cornwall and Devon as well. In Scotland, as already noticed, it lies across not only the Orcadians, but across every member of the Caledonian Old Red in Perth and Forfar, and also in the Pentlands. In Ireland the same striking fact has been described by many observers. For reasons given below, however, I am disposed to leave this unconformity out of account.

Orcadian Old Red.—The Old Red Sandstone rocks of the Moray Firth, Caithness, Orkney, Shetland, and some other areas in the north-east of Scotland, are regarded by Sir Archibald Geikie as having been laid down in a different basin of deposit from those south of the Grampians. He has proposed for this basin the name of Lake Orcadie, a name which has suggested to other geologists the very suitable adjective Orcadian, which of late years has been much used in referring to these rocks. The Orcadians consist of a vast thickness, possibly many thousands of feet, of strata, which in the main have evidently been very quietly and slowly laid down in an area of inland drainage. Dr Traquair's researches upon the fish fauna render it certain that the formation of these rocks must have occupied a very long interval of time. To the consideration of this formation we shall return presently. It will suffice to repeat the statement here,

[1] Silurian Rocks, 14,000 feet; Coniston Limestone and Borradale Volcanic Series, 12,000; Skidda Slates, 12,000+.

that where it is covered by the Upper Old Red the relationship between the two is that of a strong unconformability.

Caledonian Old Red.—To the south of the Grampians, and perhaps also to the west, occurs another area of Old Red of considerable interest and importance. These rocks are in the main also of inland lake origin, and they include as well an important group of eruptive rocks. Sir Archibald Geikie, in his important memoir "On the Old Red Sandstone of Western Europe" above referred to, regards the greater part of these as having been deposited in a lake separate from Lake Orcadie, and for which he has proposed the name Lake Caledonia. I have found it very convenient, in describing these rocks, to convert this name into an adjective, and to speak of the rocks in question as the Caledonian Old Red. The precise stratigraphical relations of the Caledonian Old Red to the Orcadian cannot be made out by field-evidence alone. But the fish fauna of the Caledonian Old Red, Dr Traquair informs us, is of a decidedly older type than that of the Orcadian — and this appears to be the case even where fish from strata high up in the Caledonians are compared with the fish from the lower horizon of the Orcadians, as if the Orcadians, as a whole, were newer than the Caledonian Old Red. In the present connection this question is one of considerable importance, for if the two are of different ages, it is quite clear that one must have been formed before the other, and we have to take the sum total of the time required for the formation of both.

Lanarkian Old Red.—In the Pentland area the Upper Old Red lies with a strong unconformity across the Caledonian Old Red Rocks, which form the mass of the Pentlands, while these, in their turn, lie with a violent unconformity upon yet another series of Red Sandstones, whose close connection with the true Silurian rocks was clearly pointed out by Sir Archibald Geikie as far back as 1860 (*Quart. Jour. Geol. Soc.*, xvi., p. 312). The interrelations of the three Old Reds in the Pentland area are admirably summed up by the same author in "Siluria," 4th ed. (1867), p. 250, in these words: "It thus appears that, between the Grampians and the Cheviot Hills, what has been called 'Old Red Sandstone'

consists of three zones—a *Lower*, graduating down into the Upper Silurian shales; a *Middle*, bounded both above and below by an unconformable junction; and an *Upper*, which shades up into the Carboniferous Rocks." This relationship is most clearly and accurately shown upon the "Horizontal" Section of the "Geological Survey of Scotland," Sheet 3, of which Sir Roderick Murchison gives a condensed diagram-section in "Siluria," 4th ed., p. 249.

Chronological Value of the Old Red Unconformities.—It appears to me that the complicated relationships existing between these several groups of strata do not warrant us in assuming, in this case at any rate, that we should be right in adding on to the time required for the actual formation of each subdivision of the Old Red other intervals of time which the unconformities would seem to imply. We are quite justified in taking it for granted that Sir Archibald Geikie's suggestions upon this point offer us a satisfactory explanation of some of the chief difficulties. According to this view, deposition and upheaval went on simultaneously in *closely adjacent* areas, so that older rocks were folded upward, and underwent denudation along one zone of the surface; while along a parallel zone, not many miles away, a downward phase of the terrestrial undulations gave rise to the conditions suitable for deposition. I have endeavoured to show elsewhere[1] that this was probably also the case in later Ordovician times in the north-west of England, where at one part there appears to be a perfectly unbroken succession from Lower Ordovician into Upper, while along another zone rocks of Bala age were deposited upon the upturned edges of the Lower Skidda Slates (? Upper Cambrian).

In the case of the unconformities connected with the various Old Reds, it appears to me that the facts warrant us in going further than this, and in assuming that the undulations to which Sir Archibald refers were not simple up-and-down movements confined to particular localities, but that they actually progressed in course of ages from one part to another. Early in the Silurian Period, according

[1] "On the Stratigraphical Relations of the Skidda Slates," Proc. Geol. Assoc., vol. ix., No. 7.

to this view, an upward phase of undulation was established along a line nearly coincident with the structural axes of the present Southern Uplands of Scotland, the septum lying parallel to that, perhaps only a few miles to the north, and the main axis of depression farther north still. The effect of a gradual upheaval of that kind would eventually be to cut off, by slow degrees, the marine area in which the normal Upper Ludlow Rocks were in process of deposition, from the area to the north, which eventually passed into a lagoon. In this latter was deposited the material derived from the waste of the uprising area to the south, which went to form the red sandstones, whose remains are so well seen in Lanarkshire, and again in the heart of the Pentlands. In dealing with these several Old Reds, I have long found it convenient to distinguish this lowest member of the series from the others by some special name. As the rocks are best seen in Lanarkshire, where their true relations were first made out by Sir Archibald Geikie, I have ventured to term the whole of this lowest Old Red series the LANARKIAN Series. Probably most people will recognise the similarity of their stratigraphical relations to those of the Glengariff Grits, on the one hand, and to the Foreland Sandstones, or Lower Devonian Rocks, on the other; and as with these, some doubt may be entertained by many as to whether they should be classed as Ludlow or as a lower member of the Devonian series. What the full thickness of the Lanarkian Rocks was when complete we have no means of knowing; but I ventured to suggest during the Edinburgh Meeting of the British Association that the missing higher members of the series may at one time have included a band of marine limestone. Numerous blocks of such a limestone, containing an assemblage of fossils remarkably like those of the Devonian Limestone of Plymouth, occur in the conglomerate which unconformably overlies the Silurian and Lanarkian Rocks. Its Brachiopoda were at one time identified as Devonian by Davidson, and many of its numerous corals are certainly, to say the least of it, closely allied to those of the Devonian Rocks. On the other hand, it is unlike any Silurian Limestone yet discovered in Scotland.

Whether this represents a true Devonian Limestone in Scottish areas is, of course, open to question; but whether it does or not is immaterial for our present purpose. I conceive that a downward phase of undulation slowly advancing northward, went on concurrently with the northward advance of the axis of upheaval that originated to the south. Eventually this axis of upheaval reached the area where the Lanarkian Rocks had been deposited, and then they, in their turn, underwent denudation as they were carried upward by the advancing wave, and the products of their denudation, in turn, supplied materials for the Caledonian Rocks, which were then in process of deposition farther north. The upheaval referred to must have been considerable, for the Lanarkian Rocks are very greatly disturbed and crumpled—all of which implies *time;* for I presume that no geologist is prepared to maintain that any disturbances sufficiently intense to throw rocks into the vertical position, or even to invert them, could well take place anywhere near what was the surface for the time being. After a considerable denudation, a downward phase of undulation, which had been slowly travelling northward, reached the spot where the Lanarkian Rocks now lay, and then they were covered by the conglomerates which lie at the base of the Caledonian Old Red in the Pentlands, and eventually by the great volcanic series itself.

If the reader can conceive of a succession of such undulations travelling from the south northward, depressing one area after another in its progress from south to north, he will have little difficulty in realising the nature of the changes to which the various Old Reds, from the Lanarkian to the top of the Upper Old Red, are due. This view will explain how it happens that the Orcadian Rocks nearly, but not quite, pass upward conformably into the Upper Old Red; and, as Mr Peach has remarked, if we could trace the Orcadians perhaps only a short distance beyond the northern limit of the British Isles, we should probably be able to discover a perfect passage from these into the true Upper Old Red.

In dealing with this part of the subject, therefore, I am

disposed to assign a comparatively small chronological value to the Old Red unconformities, as they appear to be due to undulations of much smaller wave-length, greater amplitude, and higher frequency, than we have reason to believe prevailed during many other periods. The nearest parallel case in progress at the present day seems to me to be the zone of country which embraces the Nile Valley and the borders of the Red Sea, where, apparently, terrestrial undulations of the same nature are throwing the earth's surface into close alternations of upland area and area of depression.

According to the view here taken, the time required for the formation of the Lanarkian Rocks, and their probable chronological equivalents the Glengariff Grits, is counted partly with that occupied by the formation of the Ludlow Rocks, partly with that of the lowermost part of the Caledonian Old Red; while to the time represented by the formation of the Caledonian Old Red (20,000 feet or more) will probably have to be added that represented by at least the upper half of the Orcadian Rocks, of the full thickness of which perhaps not more than two-thirds at present remain.

The true measure of time represented by the rocks at present referred to could be estimated probably with the nearest possible approximation to accuracy, if we knew the maximum thickness of marine limestone formed in the interval between the close of the Ludlow Period and the commencement of the Carboniferous. All we can say upon this point is that in the Continent at least 20,000 feet of marine strata of various kinds are referred to this horizon, and of these at least 5000 feet consist of marine limestone. There does not appear yet to be any precise figures in relation to this; but assuming that only 5000 feet of marine limestone were formed during the period when so many physical and biological changes went on in other parts, that alone gives us for the Devonian Period a time interval of 125,000,000 years. It may be remarked here that, where the Devonian Limestone attains this exceptional thickness, no unconformity can be traced between the Silurian Rocks and the Carboniferous. I have therefore taken no account

of the unconformities in Britain, vast and otherwise important as they undoubtedly are. Biologists taking note of the many and important changes in life that took place during the Devonian Period will probably all agree that this interval, vast as it seems, is yet not more than sufficient to account for the biological phenomena observed.

Silurian (Salopian) Rocks.—In the English Lake District the Salopian Rocks, stated in ascending order, consist of (1) a conglomerate lying in places unconformably upon the Ordovician Rocks; (2) Graptolitic Mudstone, which, although rarely exceeding 50 feet in thickness, yet shows by both its lithological character and the organic changes recorded by its fossils, that its deposition must represent an interval of time of enormous length. This is almost certainly a deep-sea deposit, one probably formed on the very outer verge of the zone of terrigenous deposits of its time. Above this lies the Pale Slates, a rock whose lithological character also suggests that it had a deep-sea origin, and therefore that it also accumulated at a very slow rate. The aggregate thickness of these two is rarely more than 600 feet. Judging by the organic changes which took place in the interval between the commencement of the Graptolitic Mudstones and the close of the formation of the Pale Slates, the time implied must far exceed that required for the formation of the 12,000 feet of terrigenous deposits which make up (No. 3) the remainder of the Salopian Rocks of Westmorland.

About one-third of No. 3 consists of fine-grained greywackes, which contain a high percentage of quartz particles, and which, therefore, have probably been laid down as a fringe not very far from the margin of the old land, and, in consequence, at a comparatively rapid rate. The remaining two-thirds are of a more argillaceous character. Perhaps it would be safe to regard these rocks as consisting of two-thirds of rocks which were originally loams, and one-third which may be regarded as clays. The whole, of course, is of marine origin. From top to bottom this vast pile of rocks shows evidence of quiet deposition—a view of their mode

of origin which receives further support from their uniformity of lithological character over large areas, and the fineness and evenness of their lamination. Their fossils, again, point to much the same conclusion.

We certainly have no reliable data on which to found an estimate of the time required for the formation of this enormous accumulation of marine deposits. The greywackes *may* have been formed at the rate of 1 foot in 2000 years; which, as their estimated thickness is 8000 feet, gives us 16,000,000 years for the whole of this section. The more argillaceous portion, which may be set down as about one-third of the entire thickness, *i.e.*, 4000 feet, must have been formed at a slower rate. If we set this rate at probably 1 foot in 3000 years, we shall be within the mark. This gives us an additional 12,000,000 years; making a total of 28,000,000 years for the Middle and Upper Salopians.

As for the time required for the accumulation of the deep-water graptolitiferous beds and the deep-sea clays which now form the Pale Slates, we can only judge by analogy. If the rate of palæontological change may be taken as a guide, then these two subdivisions of the Lower Salopian must have taken longer to form than the whole of the overlying 12,000 feet of greywackes and argillites. This view will, I am sure, commend itself to all palæontologists, and to the majority of the geologists who have studied these rocks in the field. I shall therefore add another 28,000,000 years for the formation of the rocks in question.

Unconformity at the Base of the Salopian Rocks in Shropshire and elsewhere.—Near Moffat, and at one or two other localities in Scotland, there is no clear evidence of any great physical break between the Salopian Rocks and the Ordovicians — probably because deep-sea conditions persisted there throughout the whole period from Arenig times to near the end of the Lower Salopian. In Ayrshire the break between the two is more marked. In Craven, as Professor Hughes showed many years ago, a well-marked unconformity exists—one to which I am myself disposed to

attach much greater importance even than he did. In South Wales the unconformity between the Salopian and Ordovician Rocks is very pronounced. But it is in Shropshire, and especially in the Longmynd area, that the evidence of a break of enormous extent is most clearly to be seen. There the May-Hill, Llandovery, or Lower Salopian, beds are seen to overstep the edges of every member of the Ordovician Rocks, themselves 15,000 feet in thickness—the whole of the Cambrians, 3000 feet or more—and, finally, they overstep the edges of the older Longmyndian Rocks, whose thickness cannot be less than 8000 feet, and may well be between twice and three times that thickness. Taking the lowest estimate, this gives us for the total thickness of rock overstepped by the Salopians in the Longmynd area 26,000 feet (or possibly half as much more than that).

There can be no question here of *overlap* to any appreciable extent, as the Pentamerus Beds are present over nearly the whole area, which shows that we are not dealing with a case either of deposition of marine strata on the flanks of an old island, or of deposition in an area of very unequal subsidence. Nothing can be clearer than the evidence that the whole of the unconformity is pre-Salopian. But, on the other hand, there is abundant internal evidence to show that the whole of this vast hiatus cannot be referred to denudation following the close of the Ordovician Period. On the eastern side of the Longmynd area, at Caer Caradoc, the Bala Rocks repose directly upon rocks of Tremadoc age—the intermediate rocks of Lower Ordovician age, fully 10,000 feet in thickness within a short distance of this spot, being here entirely absent. Mr Watts informs me in a letter that in places the Salopian Rocks lie even upon the rocks of Longmyndian Age. Part, therefore, of the enormous gap occurring at the base of the Salopian in the Longmynd area is referable to an unconformity of pre-Bala age. I have mentioned above that the equally vast unconformity at the base of the Upper Old Red in the English Lake District is referable, in like manner, to the cumulative effect of several unconformities of widely different ages. The unconformity at the base of the Upper Ordovician

Rocks has a much wider extension than appears hitherto to have been recognised.

Returning to the Longmynd unconformities: we find the Cambrian Rocks themselves, in their turn, overstepping the edges of the old Pre-Cambrian Rocks of the Longmynd, and they are known to lie even upon the edges of a series of eruptive rocks—the Uriconians—which many competent geologists regard as unconformable below the Longmyndians themselves.

Ignoring these older unconformities, therefore, we need at this point only take into account the thickness of strata which there is reason to believe was removed by denudation after the close of the Ordovician Period, and prior to the deposition of the Lower Salopian Rocks. Taking this amount at 4000 feet, as shown by the Survey sections, this, at the average rate of denudation here employed, gives us an additional 12,000,000 years.

Time required for the Formation of the Upper Ordovician Rocks.—Confining our attention for the present to the Upper Ordovician Rocks of the Longmynd area, we find, from a measurement of the Geological Survey "Horizontal" Sections, that these rocks are fully 4000 feet in thickness, and consist mainly of marine sediments, together with some volcanic rocks. The general character of the series as a whole is suggestive of quiet deposition, while the changes in the faunas as the rocks are traced from below upward, point unmistakably to a great length of time. If we assume that, as a whole, this series was formed at no greater rate than that of 1 foot in 3000 years (which in this case, as in others of the same nature, seems to me to be a rate far too rapid), 4000 feet would require 12,000,000 years.

Unconformity at the Base of the Bala Series.—Considering that the Longmynd district has been repeatedly the centre of axes of upheaval, and considering, further, that volcanic action was rife throughout the older period there, it seems to me advisable to regard the unconformity which brings the Bala Rocks into direct contact with the Tremadoc strata on the east side of Caer Caradoc, as probably due to contemporaneous disturbances and upheavals of the same nature as

those originally described by Sir Archibald Geikie in connection with the Lanarkian and Caledonian Old Reds; and, still more to the point, of the same nature as those I described in my paper "On the Stratigraphical Relations of the Skidda Slates,"[1] in which rocks of Bala age have been made to lie upon the upturned edges of the Tremadoc and older rocks of the northern side of the English Lake District; and, again, in the case of the Bala Rocks in Ireland, which repose upon the upturned ends of the Cambrians. I do not therefore consider that we are fully justified in counting the unconformity specially under notice, as it is probably, in part at least, contemporaneous in time with the Bala Rocks themselves.

Time required for the Formation of the Older Ordovician Rocks.—Still confining our attention to the Ordovician Rocks of the Longmynd area, we find that the collective thickness of the Llandeilo[2] and Arenig Rocks there is, according to the Survey "Horizontal" Section, fully 16,000 feet. Here again the rocks consist largely of marine strata, amongst which graptolitiferous mudstones bulk largely. This is especially true of the upper part of the series. The lower part, still marine, includes a large percentage of volcanic material, and, moreover, contains quartz-particles in abundance. But if we consider that the more rapid formation of the lower strata is compensated, or more than compensated, by the slow rate of accumulation of the upper, as evidenced by both its mineral character and the biological changes of which its fossils present a record, we should be well within the mark if we estimate that the formation of these Lower Ordovician Rocks, as a whole, went on at the average rate here assumed, *i.e.*, 1 foot in 3000 years. At this computation these rocks add 33,000,000 years to our roll.

Time implied by the Cambrian Period.—In general, the Lower Ordovician Rocks pass down conformably into the underlying Cambrians. In North Wales, near Harlech,

[1] Proc. Geol. Assoc.

[2] I employ the term Llandeilo for those strata which occur below the pre-Bala unconformity, and which conformably succeed the rocks of Arenig age.

the Cambrian Rocks, properly so-called, are certainly not less than 13,000 feet in thickness. The Harlech and Llanberis Rocks, measured up to the base of the Menevians, are, according to my calculation on the ground, a little over 6000 feet. To this we have to add 200 feet for the Menevians, 5150 feet for the Lingula Flags, and 2000 feet for the Tremadoc Rocks. This gives a total thickness for the Cambrians of 13,350 feet, which is, if anything, below, rather than above, the mark. The Harlech beds are largely quartzitic, and may have been formed at a somewhat more rapid rate than that generally taken into computation here. On the other hand, the remaining strata consist largely of what must originally have been fine marine loam, mud, and clay, which were slowly and quietly deposited at some distance from the land. In dealing with these Cambrian Rocks, I should be disposed to modify the figures used generally in the foregoing computation, and to allow a somewhat higher rate for the formation of the Harlech and Barmouth Rocks, seeing that these consist largely of a coarse greywacke. If we set their rate of accumulation at 1 foot in 1000 years, this would probably be a fair average, seeing that these rocks include argillaceous bands in the proportion of about one-fifth of the whole. Taking their collective thickness at 6000 feet, this gives us 6,000,000 years.

The overlying Menevian strata contain a widespread, if thin, deposit of manganese ore (which, by the way, is a true bed, and not a vein), whose general aspect lends additional confirmation to the view suggested by its fossils that in this case we are dealing with a deep-sea deposit. It has already been stated that the petrographical nature of both the succeeding Lingula Flags and Tremadoc Rocks is also suggestive of quiet and slow deposition—a view equally well borne out by the fossils which occur in these rocks. I was so much impressed by these features when studying these rocks in North Wales a few years ago, that I should feel quite justified in setting their rate of formation at 1 foot in 5000 years. Their aggregate thickness in North Wales is 7350 feet, which, at the rate suggested, gives us a period of 36,000,000 years.

The Durness Limestone.—It happens in the case of the rocks of Middle and Upper Cambrian age that we are able to a certain extent to check the computation regarding their age by figures obtained from another source. In the north-west of Scotland the rocks containing *Olenellus* and a Lower Cambrian fauna (which correspond in time with the upper part of the Harlech Rocks) are overlaid by a thick mass of marine limestone—the Durness Limestone—whose higher beds yield fossils with a Tremadoc facies. This limestone would therefore seem to be the equivalent in time of all the North Wales strata from the base of the Menevian to the top of the Tremadocs. Mr Peach tells me it may be from 1500 to 2000 feet in thickness or even more, as its top is not known for certain. Relying upon these lower estimates, it would seem that the 7350 feet of argillaceous beds in North Wales are chronologically equivalent to 1500 feet of limestone in the north-west of Scotland, which is in the proportion of about four and a half of fine marine mud to one of limestone—a proportion which seems to hold good in other cases than this. If we take the time requisite for the formation of the Durness Limestone at 1 foot in 25,000 years, this gives us 37,500,000 years, which is an estimate not very different from that arrived at in connection with the Cambrian Rocks of North Wales.

Adding to this estimate the time required for the formation of the Lower Cambrian Rocks of Wales, we get for the whole Cambrian Period 42,000,000 years.

Summary regarding the Age of the Lower Cambrian Rocks;—

	Time in Years.
From the Commencement of the Tertiary Period to the Present Day,	93,420,000
Time represented by the Formation of the Chalk, Upper Greensand, Gault, and Lower Greensand,	31,400,000
Pre-Cretaceous Unconformity in Britain,	13,200,000
Time required for the Deposition of the Jurassic-Wealden Series,	59,400,000
Time represented by the Tyrolian and Panormian Rocks,	87,500,000
Unconformity at the Base of the Lower New Red in Britain,	45,000,000
Duration of the Upper Carboniferous Period in Britain,	31,815,000
Carry forward,	361,735,000

	Time in Years.
Brought foward,	361,735,000
Time required for the Formation of 2500 feet of Carboniferous Limestone,	62,500,000
Time represented by the Continental Devonian Limestones,	125,000,000
Duration of the Period represented by the Salopian (Silurian) Rocks,	56,000,000
Chronological Value of the Unconformity at the Base of the above,	12,000,000
Time required for the Accumulation of the Upper Ordovician Rocks,	12,000,000
Lower Ordovician Time,	33,000,000
Upper and Middle Cambrian Period,	36,000,000
Lower Cambrian Period,	6,000,000
Total since the Commencement of the Cambrian Period,	704,235,000

Concluding Remarks.—Seven hundred millions of years back from the present to the commencement of the Cambrian Period may seem to many persons far too extravagant an estimate to be for a moment seriously considered. Every one of the data upon which this estimate is founded will probably be regarded as absolutely untrustworthy, on the ground that they are avowedly based almost as much upon speculation as upon fact, and also upon the ground that I myself do not put these conclusions forward as a final answer to a very difficult question, and one which probably never will be answered with more than a very rough approximation to the real truth. If the estimate prove wrong in any particular, then the very rectification of the error in question will bring us a step nearer to the truth, and no one will rejoice more than I shall at finding what I feel is little else than a speculation, based as yet upon imperfectly-known data, replaced by facts and inferences therefrom which are of a more trustworthy character. Hypotheses have their use in Geology as much as in other branches of Science.

For my own part, I am quite prepared to find that, as our knowledge of Geology and Biology advances, we shall feel it necessary to extend rather than to abbreviate the estimate I have put forward.

Seven hundred millions of years carry us back to the

Commencement of the Cambrian Period, but not to the Commencement of Life upon the Earth. We have long known, thanks to the labours of fellow-geologists in Britain and in America, that the Lower Cambrian fauna contains representatives of all the chief forms of Invertebrate Life, and these are in most cases by no means of low zoological grade. No one who fully realises the import of Evolution as now understood can for a moment doubt that this fact points in a manner that is unmistakable to the inference that the Beginning of Life upon the Earth must be vastly more remote—perhaps as much farther back from Cambrian times as they are removed from our own. To me, to whom Geology is of interest chiefly as throwing light upon the past history of Life upon the Earth, this early appearance of highly-organised forms of Invertebrata suggests remarks sufficient to double the already considerable length of this Address. I must content myself, however, with referring the reader to the very thoughtful and suggestive address on this aspect of our inquiry which Professor Poulton delivered at the 1896 meeting of the British Association.

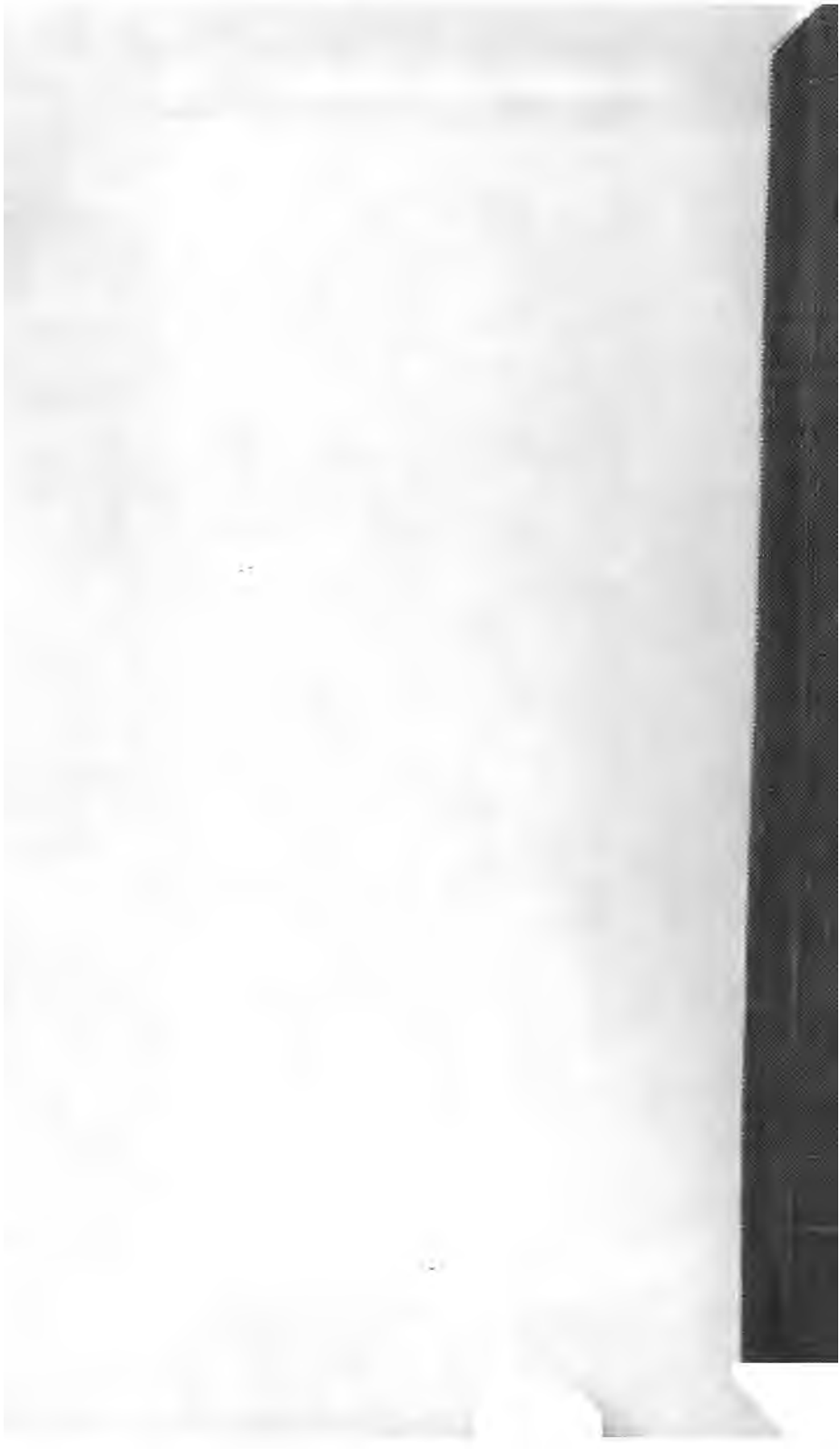
In regard to the physical and mathematical aspect of this question of the Age of the Earth, I, as neither a physicist nor a mathematician, can have but little to say. But, so far as I can judge, the late Dr Croll's "Stellar Evolution" supplied an answer to one of the main objections to any high estimate of the Earth's Age. Professor Perry, Mr O. Fisher, and others have done equally good work in the same direction, and have earned the thanks of all geologists for their labours in a good cause.

On my own part, I have only two suggestions to make, neither of which, I am told, is new, but of which both seem to me to have an important bearing upon the physical aspect of the present question. Each shall take the form of a query.

1. Is it certain that the whole of the downward increment of heat within the Earth is due to any vestige of the Earth's original heat? If not, why may not part of it be due to the conversion of the energy of motion arising from terrestrial

undulations (set up mainly by luni-solar gravitational energy) into the energy of heat?

2. Is it certain that radiant energy in general differs from gravitational energy in operating only between two solid bodies? If radiant energy acts only between any two material bodies, how do we know that the radiant energy of the sun, or the heat of the earth, is being dissipated into space at anything like the rate which is generally assumed to be the case?



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